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Use of Traffic Conflicts to Estimate Vehicle-Pedestrian Safety at Signalized Intersections

By

Hiba Nassereddine

A dissertation submitted in partial fulfillment of the

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Chapter 10 Communicating Research to Non-Expert Audiences

As scientists, our main goal is to share our research knowledge. We strive to make this knowledge available and accessible to other people in our field through scientific publication. However, it is also important to share our knowledge with a broad range of people – from our family members and friends to the general public who are a wide nonscientist audience. Hence, I wrote this chapter to describe the broader context and findings from my Ph.D. research to people outside my research field. I would like to thank the Wisconsin Initiative for Science Literacy (WISL) at UW-Madison for providing this platform, and for sponsoring and supporting the creation of this chapter. I would like to thank Professor Bassam Shakhashiri for leading this initiative, and Elizabeth Reynolds for her valuable feedback.

10.1 Why did I choose transportation engineering?

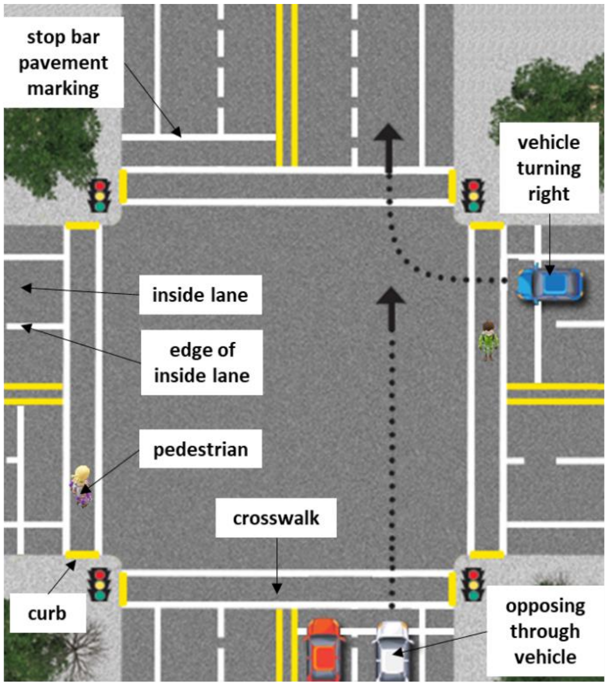
When I decided to become an engineer at a young age, I based my decision on the joy of solving math problems. In my undergraduate studies, I focused on structural engineering since it was popular, and since being a woman in a primarily male-dominated field gave me additional motivation to do it. Once I took my first course in transportation engineering, it became the civil engineering discipline I wanted to pursue. That course made me realize that transportation engineers can directly help the community by making road improvements and providing safer roads for pedestrians, drivers, and cyclists. Hence, my educational aspirations have always aimed towards acquiring a Ph.D. in transportation engineering to further allow me to pursue a career as a researcher. One year after receiving my master's degree in structural engineering, I joined the PhD program at UW-Madison under the supervision of my advisor Professor David Noyce. While working on several high-profile research projects, I realized that computer science, programming and statistical analysis skills are a must nowadays in a transportation career. To complement my transportation engineering skills, I have developed programming expertise and I completed a master’s degree in computer sciences which is proving to be beneficial for my transportation career. I also took several statistics courses. My career vision is to interact, collaborate, and coordinate with scientists, engineers, analysts as well as people from different fields in order to research, design, and implement solutions to transportation problems. My career objectives also include teaching transportation engineering courses. From my experience as a teaching assistant, I found that teaching is not only an exchange of knowledge but also the nurturing of a community. There is nothing I like more than seeing students freely collaborating, helping each other solve problems, and developing new ideas.

So why transportation engineering? Almost every day, everybody interacts with the transportation system, whether it is traffic lights, cars, pedestrians, sidewalks, or roads. A lot of people do not think about these interactions. For me, getting to learn about these interactions and how they work, and trying to make them work better is like getting in on a secret that impacts everybody’s lives.

10.2 My dissertation in a nutshell

Pedestrians are among the most vulnerable users of the transportation system, especially when crossing a roadway. In fact, in 2020, there were 6,516 pedestrian fatalities (59% increase from 2009) in the United States. According to the National Highway Traffic Safety Administration, 24% of pedestrian fatalities occurred at intersections. When pedestrians and drivers interact, a vehicle-pedestrian conflict situation is created. Given the common nature of vehicle-pedestrian interactions, there is a need for improving communication and reinforcing the right of way rules associated with these interactions. My dissertation focuses on studying the behavior of drivers turning right at a traffic signal light when there is a pedestrian in the crosswalk. I propose a new measure to evaluate the safety of traffic signals. I also propose a software-based approach to compute a safety measure and a new and innovative data collection tool.

Before I start discussing my dissertation, I would like to start by showing a figure that summarizes some of the terminologies used in this dissertation:



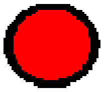
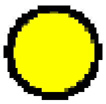
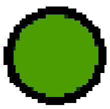
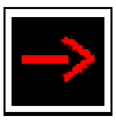
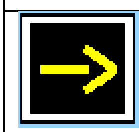
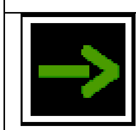
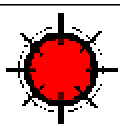
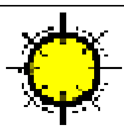
10.3 Right of way in a crosswalk

Everyone has different preferences when it comes to transportation, but at one time or another everyone is a pedestrian. Who has the right of way in a crosswalk: a driver turning right or a pedestrian in the crosswalk? There is no simple answer to this question. The answer is it depends on multiple factors and multiple rules. Consider the following scenario: You are a driver turning right and have the green light. A pedestrian is walking towards you in the crosswalk you are about to cross. If the pedestrian has just stepped off the curb, do you have to wait for them to cross? According to Wisconsin Pedestrian Laws, as a driver, you shall yield the right-of-way to a pedestrian who has started to cross on a green or "Walk" signal. Also, the law states that you, as a driver, may not begin to turn if you would endanger or interfere with a pedestrian in any way. So, going back to our scenario, what is the answer? If you have already started to turn right, and the pedestrian is far from your lane, you can proceed and turn. However, if you have not started the turn, you shall wait for the pedestrian to cross.

There are also laws for other situations such as when a driver is approaching a stop sign or a crosswalk with no signs at all. I will not go over these laws simply because my dissertation focuses on intersections with traffic lights. However, if anyone is interested, you can read more about the laws here (https://wisconsindot.gov/Documents/safety/education/pedestrian/pedlaws.pdf).

10.4 Different traffic signal lights

As I mentioned earlier, my dissertation focuses on intersections with traffic lights. So, what are the different traffic signal lights that a driver turning right needs to be aware of? This should be an easy question if you have your driver's license. However, if you do not drive and simply take the bus or are a pedestrian, you might not be fully aware of the different traffic signal lights. So, here are the main ones that a driver turning right should be aware of.

Traffic signal light	Name	Description
	Solid Red	It means STOP. You can make a right turn against a red traffic signal light after you stop and after you yield to pedestrians, bicyclists, and vehicles. Do not turn if a “NO TURN ON RED” sign is posted.
	Solid Yellow	It means CAUTION. The red traffic signal light is about to appear.
	Solid Green	It means GO. If you are turning, check for other vehicles, bicyclists, or pedestrians before completing the turn.
	Red Arrow	It means drivers turning right must STOP. You need to remain stopped until the green signal or green arrow appears.
	Yellow Arrow	It means to be prepared to obey the next traffic signal light.
	Green Arrow	It means you must turn right after you yield to any vehicle, bicyclist, or pedestrian still in the intersection.
	Flashing Red	It means STOP. After stopping, you may proceed when it is safe.
	Flashing Yellow	It means proceed with caution - slow down and be alert before entering the intersection.
	Flashing Yellow Arrow	It means you must first yield to pedestrians and then turn with caution.

A lot of people might not be familiar with the right turn flashing yellow arrow but might be familiar with the left turn flashing arrow. In fact, over the last two decades, drivers have become more used to seeing a left-turn flashing yellow arrow signal indication that reinforces the need to yield to opposing traffic movements. More recently, to reinforce the need for drivers to yield to crossing pedestrians, right-turn flashing yellow arrow signal indications have been used. This means that when a pedestrian's "Walk" signal is activated, drivers going straight will have a solid green light and drivers turning right will have a right turn flashing yellow arrow signal indication. In this case, drivers turning right have the right-of-way after they yield to pedestrians. So, let us consider the following scenario: You are a driver who wants to turn right at an intersection with a right turn flashing yellow arrow signal indication. A pedestrian is walking towards you in the crosswalk you are about to cross, do you have to wait for them to cross? In this case, you must yield to the pedestrian and wait for them to cross before you can turn right.

10.5 Safety evaluation of a traffic signal light

In general, drivers turning right must yield to pedestrians in the crosswalk. With the new implementations of the right-turn flashing yellow arrow, a question arises. How do we evaluate the safety of this indication on pedestrians? Going a step back, how do we evaluate the safety of an intersection in general? The traditional answer is a transportation party (city of Madison, WisDOT, transportation engineers) monitors the intersection for a minimum of 3 years to see how many crashes occurred and how many pedestrians died, had severe injuries, and had minor injuries. So, if the city of Madison, for example, adds a right-turn flashing yellow arrow indication to an intersection, we need to monitor this intersection for 3 years before the addition of the new indication and for 3 years after. Then engineers/researchers will compare the number of crashes and their severity and evaluate the safety of this traffic light. This traditional approach has several shortcomings.

(1) Crashes are rare events and some intersections do not have crash data.

(2) For intersections with crash data, waiting for crash data availability is a multi-year process.

(3) Crashes are not always uniformly reported, which causes data errors or incomplete records and can sometimes lead to biased conclusions.

(4) This approach does not account for scenarios in which reduction in crashes is not the only safety improvement.

To overcome these shortcomings, researchers have proposed something called surrogate safety measures (referred to as SSMs) to evaluate road/intersection safety as an alternative to using crashes as the sole evaluation tool.

10.6 What is a surrogate safety measure?

Surrogate safety measures are any measures that are physically related to crashes. They may include:

- travel time – time spent traveling to your destination
- queue lengths – number of vehicles waiting in a queue (for example, at a red light)
- red-light violations – number of vehicles who ran the red-light
- deceleration rates – the rates at which the driver slows down
- measures from traffic conflicts when more than one road user is involved

A traffic conflict is defined as an event in which two road users (two vehicles or a vehicle and a pedestrian) would crash if neither user took preventive action, or the preventative measures were not adequate. A conflict between a vehicle and a pedestrian can occur when a pedestrian crosses in front of a vehicle that has the right-of-way or when a driver is turning and a pedestrian is in the crosswalk.

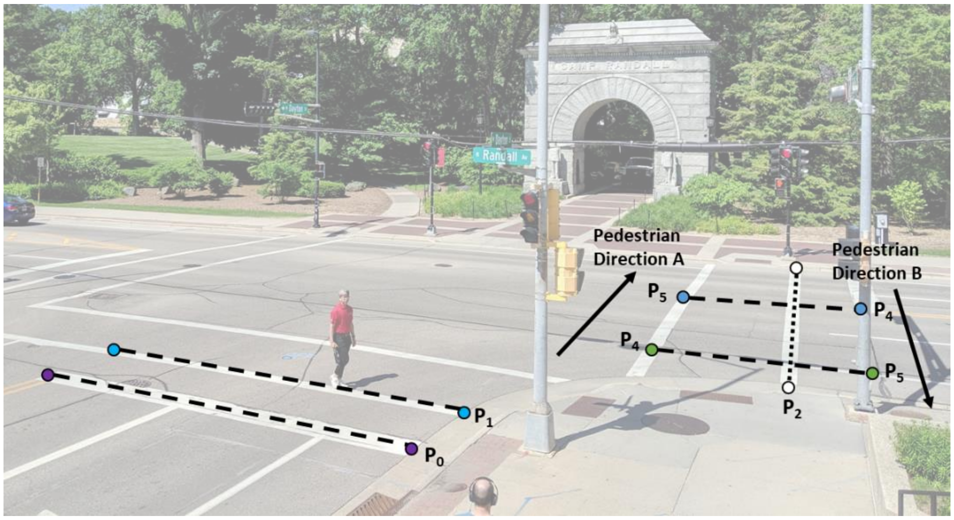
For the interactions between vehicles and pedestrians, one of the most common surrogate safety measures is called Time-to-Zebra: the remaining time for the driver to reach the crosswalk when the pedestrian is located at the edge of the curb. For my dissertation, my first topic is to introduce a new safety measure that relates to drivers and pedestrians.

10.7 Topic 1: Propose time to complete a right turn as a new surrogate safety measure

A driver that approaches an intersection and starts the process of completing a right turn when a conflicting pedestrian is present on the crosswalk must decide if the path they would normally follow is safe. From a theoretical perspective, if the driver does not hit the pedestrian, then the interaction was safe. However, the decision for the driver is more complex as the driver must determine if maintaining the path they would normally follow provides a sufficient level of comfort in negotiating the turn with the pedestrian. If the driver perceives a potential collision, they will reduce their speed or come to a complete stop before continuing the turn.

The time for a driver to complete a right turn depends on several factors, and mainly on the position of the pedestrian within the crosswalk. Therefore, as an indicator of safety, I propose the use of the time it takes drivers to complete a right turn based on the position of the pedestrian within the crosswalk to describe the level of “respect” that drivers have for pedestrians.

The first step to conducting such research is to collect data. In June 2018, I installed a handheld camera next to the intersection of North Randall Avenue and West Dayton Street. The camera position allowed me to observe and document the moment when the front axle of a vehicle crossed the P_0, P_1, and P_2 positions shown in the figure below. The position of the camera also allowed me to document the moment when a conflicting pedestrian crossed P_4 and P_5 which are also shown in the figure below. I recorded the intersection for a total of 18 hours, over multiple days for 3 hours a day. I recorded the intersection during periods of low pedestrian and vehicle activity.



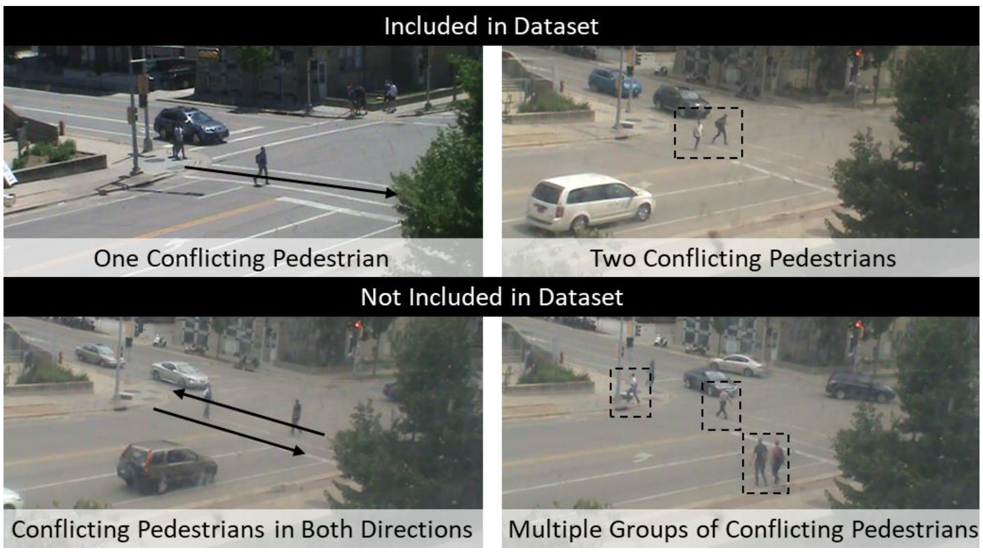
Visual Representation of Timestamps Documented (Not Data Collection View)

After recording the intersection, I watched the videos one by one using the *mpv* video player, and I logged the timestamps associated with positions P_0, P_1, P_2, P_4, and P_5. The figure below shows an example of logging a timestamp. I also documented how many pedestrians were crossing, the pedestrian direction of travel (A or B), the traffic signal light when the driver started the turn (green or red), and whether the driver stopped at the stop bar pavement marking before starting the turn (Yes or No).

Screenshot of Timestamp Extraction Process

I did not capture every single right-turn movement. I limited my observations to the following cases:

- A leading right-turning vehicle in which a vehicle completed the right turn at least 5 seconds after another vehicle completed the same right turn
- Right-turns made when no pedestrians were present or when 1, 2, or 3 pedestrians entered the crosswalk at the same time and in the same direction

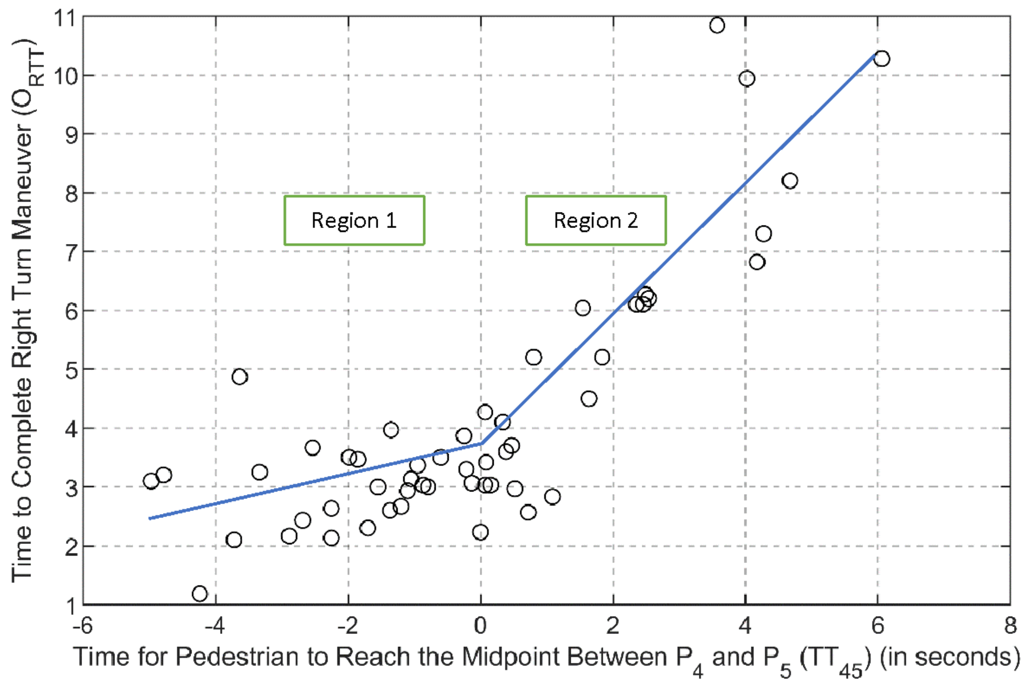


Sample Interactions Included and Not Included

I calculated the time to complete a right turn by subtracting the timestamp of P_1 from the timestamp of P_2. I ended up with 26 observations when a driver completed a right turn with no pedestrian crossing and 52 observations when a driver completed a right turn with a pedestrian crossing. On average, drivers need 2.01 seconds to complete a right turn when there is no pedestrian crossing. On the other hand, when pedestrians were present, it took drivers on average 4.16 seconds to complete the right turn. This value is approximately 2 times the average value when no pedestrian was present. This means that the presence of a pedestrian causes the driver turning right to take longer to complete the right turn.

I also calculated the time it takes the pedestrian to reach the midpoint between P_4 and P_5. Then, I subtracted this value from the timestamp of when the driver was at P_1. If this new value is negative, it means the pedestrian is walking away from the midpoint, and if it is positive, it means the pedestrian is approaching the midpoint. Why did I choose the midpoint as a reference point? Because, theoretically, the midpoint can be treated as the physical point within the crosswalk where pedestrians are the most vulnerable.

As I mentioned before, I want to use the time to complete a right turn as a function of the position of the pedestrian within the crosswalk to describe the level of "respect" that drivers have for pedestrians. How do I do that? I simply create a plot that shows the time to complete the right turn maneuver (on the y-axis) as a function of the time for the pedestrian to reach the midpoint between P_4 and P_5 when the driver reached P_1 (on the x-axis) (figure below). Each circle is an observation, so in total, this plot has 52 observations. If we look at the plot, we see that the circles are grouped together, and we can split the plot into two regions: the first one when the time for pedestrians to reach the midpoint between P_4 and P_5 is less than 0 and the second one is when the time for pedestrians to reach the midpoint between P_4 and P_5 is greater than 0. Using a statistical technique called linear regression, I can have an equation for a line that can connect the circles of each region.



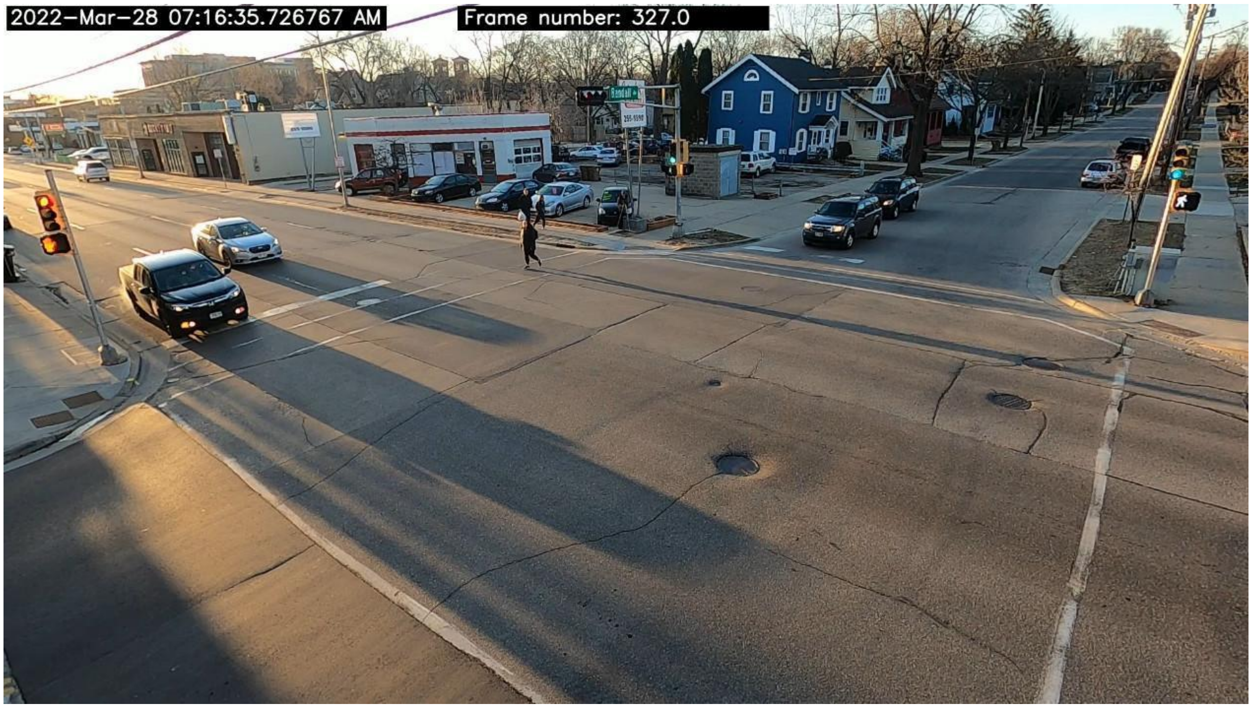
We can see a sharp difference in the steepness (called slope) of the two lines. The change in slope between the two regions can act as an indicator of the additional “respect” exhibited towards pedestrians that are approaching the midpoint. In other words, when a driver sees a pedestrian approaching the midpoint, it takes a longer time to complete the right turn, hence, they show more “respect” towards the pedestrian.

Using another statistical method called multiple linear regression, we can learn what affects the right turn. In addition to the position of the pedestrian in the crosswalk, I found that the pedestrian’s direction of travel (A or B), and whether the driver stopped at the stop bar pavement marking before starting the turn (Yes or No) affect the time it takes a driver to complete a right turn.

10.8 Topic 2: Evaluate the safety of right-turn flashing yellow arrow in two different methods

10.8.1 Method 1

After demonstrating how I can use the time to complete a right turn to describe the level of “respect” that drivers have for pedestrians, I want to use this new surrogate safety measure to evaluate the safety of a right turn flashing arrow. For the first method, I will create a similar plot as before for the right-turn completed at a solid green and right turns completed at a right turn flashing yellow arrow. Again, the first step is to collect data. This time, I chose the intersection at North Randall Avenue and Regent Street and the intersection at West Dayton Street and North Park Street because they both have solid green signals. As for the intersection with the right turn flashing yellow arrow, I chose East Johnson Street & North Blair Street. I used GoPro Cameras that I mounted to a flagpole, and I attached the flagpole to the traffic pole using clamps (figure below). This time, I recorded video data for each right turn movement of each intersection. I recorded North Randall Avenue and Regent Street for a total of 15 hours over 5 days in March 2022, West Dayton Street and North Park Street for a total of 9 hours over 3 days in May 2022, and East Johnson Street & North Blair Street for a total of 24 hours over 8 days in April 2022.



Like before, I computed the time it takes drivers to complete a right turn with and without pedestrians. I also calculated the time it takes pedestrians to reach the edge of the inside lane. The reason I picked the edge over the midpoint was because some approaches had 1 lane in a direction while others had 2 lanes. The edge of the lane in this case is the critical point for pedestrians. I also documented how many pedestrians were crossing, the pedestrian direction of travel (A or B), and whether the driver stopped at the stop bar pavement marking before starting the turn (Yes or No). I also used some computer science skills and extracted the pedestrian speed, vehicle speed, and vehicle deceleration every 0.1 seconds.

As I mentioned before, I recorded two intersections that had solid green for the right turn because I want to show that my method works on different intersections. However, I also needed to pay attention to the geometric features of each intersection. The radius of each right turn might be different. I wanted to combine all right turns made on a solid green, but I first needed to check if I could do that. To better understand how I can combine all these turns on the solid green, I will compare them to apples. I can easily group apples into two groups: green vs red. Granny smith apples and Crispin apples are green apples that have similar tastes even though they do not have the same appearance. So based on taste, I can group them together. I cannot taste a right turn, but I can use a statistical test called t-test, to see how similar the right turns are from different intersections. In the case of my selected intersections, the radii were so similar that I was able to combine all the turns made on a solid green together.

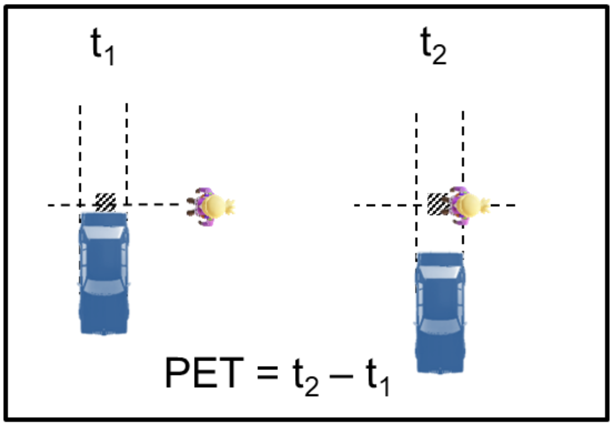
On average, when no pedestrians were present, drivers took 2.11 seconds to complete the right turn on a solid green and 2.20 seconds on a right turn flashing yellow arrow. When pedestrians were present, drivers took 3.31 seconds on a solid green and 5.44 seconds on a right turn flashing yellow arrow. I then plotted the time to complete the right turn maneuver (on the y axis) as a function of the time for pedestrians to reach the edge of the lane when the driver reached P_1 (on the x-axis) (figure below). Like before, we can split the plots into two regions: the first one when the time for pedestrians to reach the edge of the lane is less than 0 and the second one is when the time for pedestrians to reach the edge of the lane is greater than 0.

Looking at the slopes of the lines, the orange lines (representing the right turn flashing arrow) are steeper/sharper in both regions than those of the green lines (representing the solid green). The sharper lines indicate that drivers turning right exhibit additional "respect" towards pedestrians that are approaching the edge of the lane when there is the right turn flashing arrow. I decided to call the slope of the line Pedestrian Respect Indicator. We can compute this indicator value for different intersections, the higher this value is, the higher the respect is for pedestrians.

I also used multiple linear regression to determine what affects the right turn. In addition to the position of the pedestrian in the crosswalk, I found that the pedestrian direction of travel (A or B), whether the driver stopped at the stop bar pavement marking before starting the turn (Yes or No), and the deceleration rate of vehicles affect the time it takes a driver to complete a right turn.

10.8.2 Method 2

For the second method, I used the new surrogate safety measure I proposed which is the time to complete the right turn, along with another measure to predict the number of crashes at these 3 intersections. The other safety measure is called post-encroachment time (PET). It can be explained in the figure below. We record the time at which the rear bumper of a vehicle turning right arrives at a conflict point, and then we record the time at which the pedestrian arrives at that point. We take the difference which gives post-encroachment time ($PET = t_2 - t_1$).



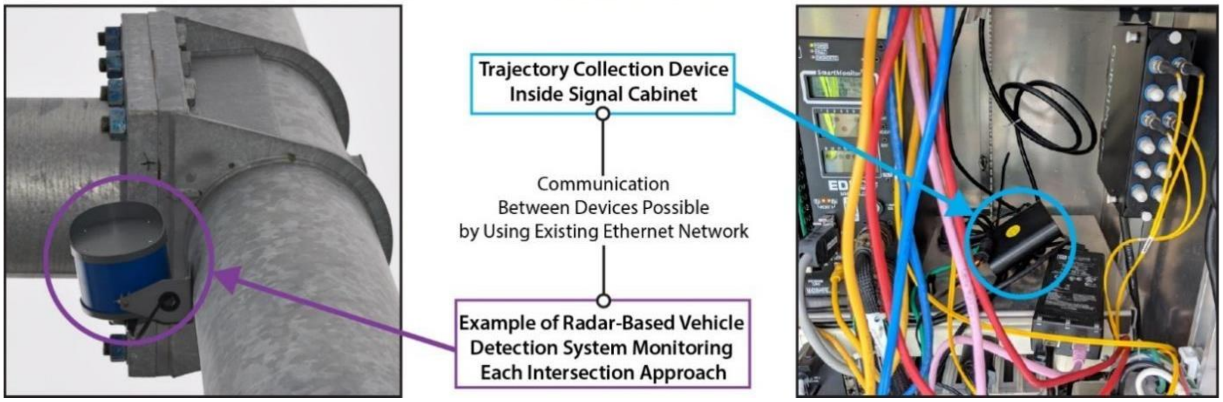
I used a statistical method called extreme value theory and I used the time to complete a right turn, post-encroachment time, pedestrian position in the crosswalk, pedestrian direction of travel (A or B), and whether the driver stopped at the stop bar pavement marking before starting the turn (Yes or No), and the deceleration rate of vehicles to predict the number of crashes.

To check if the predicted numbers are accurate, I had to compare them to the actual observed number of crashes. I obtained the actual observed number of crashes from a crash database called WisTransPortal. WisTransPortal contains information on all reported crashes in Wisconsin from 1994 through the current year. I checked the actual observed number of crashes for the years 2017 and 2018 for each intersection. The intersection at North Randall Avenue and Regent Street had on average 0.5 crashes per year, the intersection at West Dayton Street and North

Park Street had 1 crash per year, and the intersection at East Johnson Street & North Blair Street had 0.5 crashes per year. My best model predicted that the intersection at North Randall Avenue and Regent Street would have 0.47 crashes per year, the intersection at West Dayton Street and North Park Street would have 0.91 crashes per year, and the intersection at East Johnson Street & North Blair Street would have 0.60 crashes per year. These numbers are very close to the actual numbers. Why is this important? Although these intersections had crash data, as I mentioned before many intersections do not. I can now use my model to predict the number of crashes for such intersections and evaluate the safety of a traffic signal or a traffic sign even.

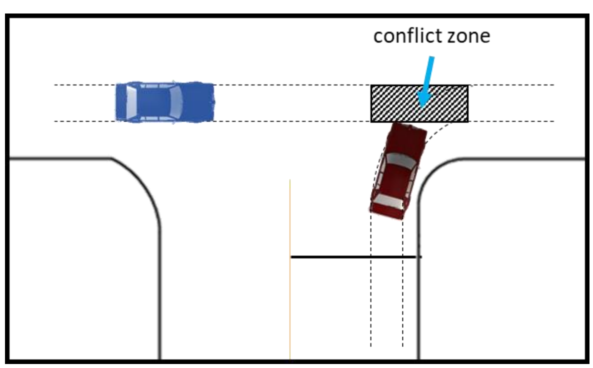
10.9 Topic 3: Propose a software-based approach to calculate surrogate safety measures

To calculate post-encroachment time for the previous topic, I had to watch hours of videos and log the corresponding timestamps. From there, I can write some code to detect vehicles and pedestrians and then track them. But I still need to use some computer vision techniques to extract the position of the vehicles and pedestrians, then convert those positions from pixel (video coordinates) to feet distances (real-world coordinates). Finally, I can get the corresponding timestamps to calculate post-encroachment time. This takes time and requires a high-performance computer. I wish there was a device that could give me all this information. Actually, there is! Radar-based vehicle detection system is a device that can be attached to a traffic pole to detect moving or stationary objects such as vehicles. Radar detectors can continuously monitor vehicles approaching the intersection and provide accurate information related to speed, position, and time.

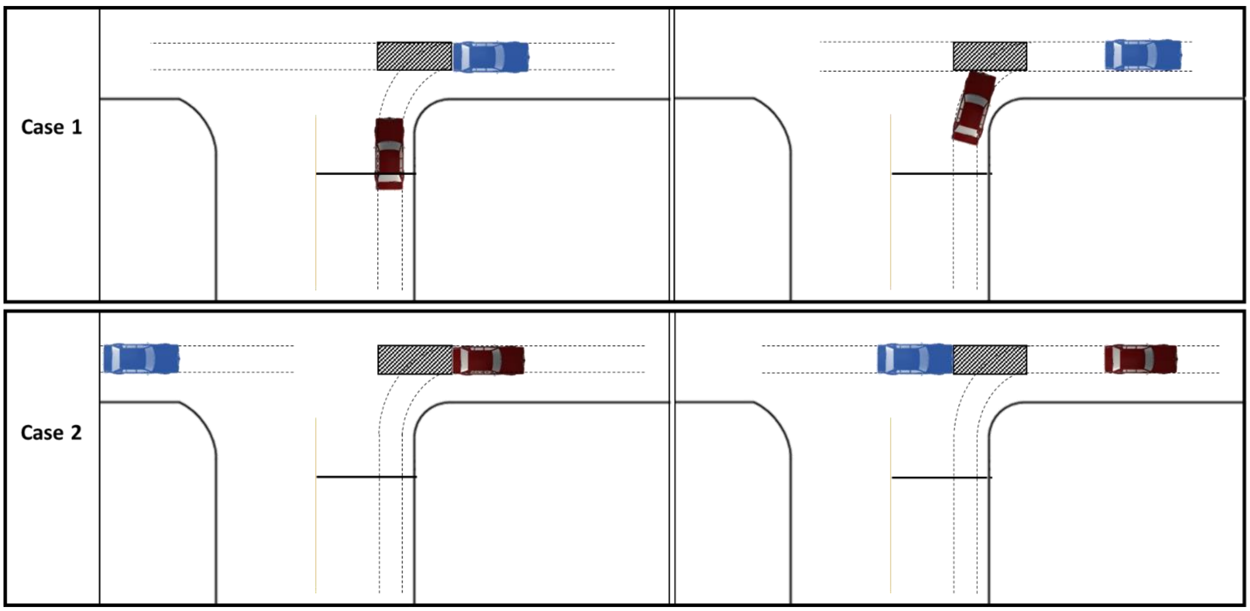


I decided to develop a software-based approach to automatically compute post-encroachment times between vehicles turning right on red (red vehicle in figure below) and opposing through vehicles (vehicles going straight and have a solid green – blue vehicle in the figure below). I used data collected from East Northland Avenue and North Meade Street intersection in the City of Appleton on January 9, 2018, from 7 to 10 am. I also obtained video recordings from a security camera installed near the intersection. I watched the video, and I manually calculated the post-encroachment times between vehicles turning right on red and opposing through vehicles to validate my software computations.

I first had to identify the conflict zone shown in the figure below. The conflict zone is downstream of the stop bar of the right-turning vehicle approach and upstream of the stop bar of the conflicting-through vehicle approach.



I also have two types of possible cases for post-encroachment times calculation for a right-turning vehicle and a conflicting-through vehicle. The first case is when the conflicting-through vehicle arrives at the conflict zone first. The second case is when the right-turning vehicle arrives at the conflict zone first (figure below). I used the position of vehicles and their speeds to identify vehicles turning right on-red and the conflicting vehicles going straight. Once I identified the pair of vehicles, I extracted the required timestamps and calculated post-encroachment times.

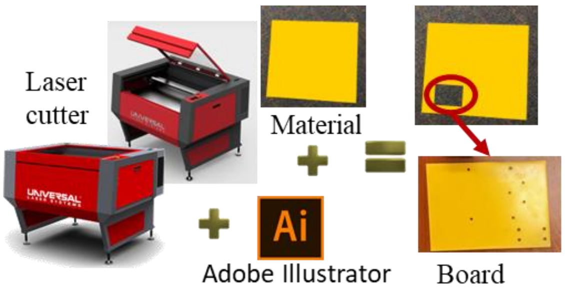


Finally, I compared the values from the videos and the values from the software-based approach. The values were very close, which means we can rely on vehicle-based detection systems to compute surrogate safety measures.

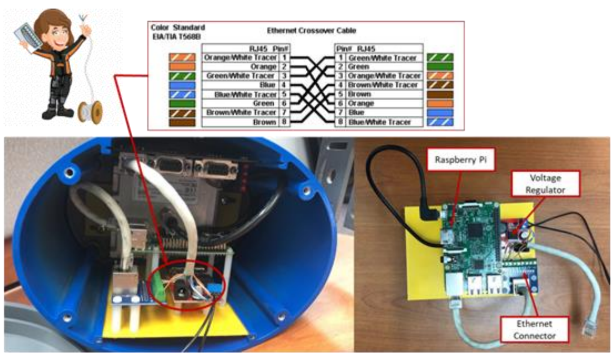
10.10 Topic 4: Create a new data collection system

As we saw before, video recordings and radar-based vehicle detection systems can provide very useful information to transportation engineers/researchers. So, combining both systems would allow us to have better data about the transportation system. For the last part of my dissertation, I created a new and innovative data collection method by adding a camera to the radar-based vehicle detection system (Intersector™ manufactured by MS Sedco). This was a very fun part of my

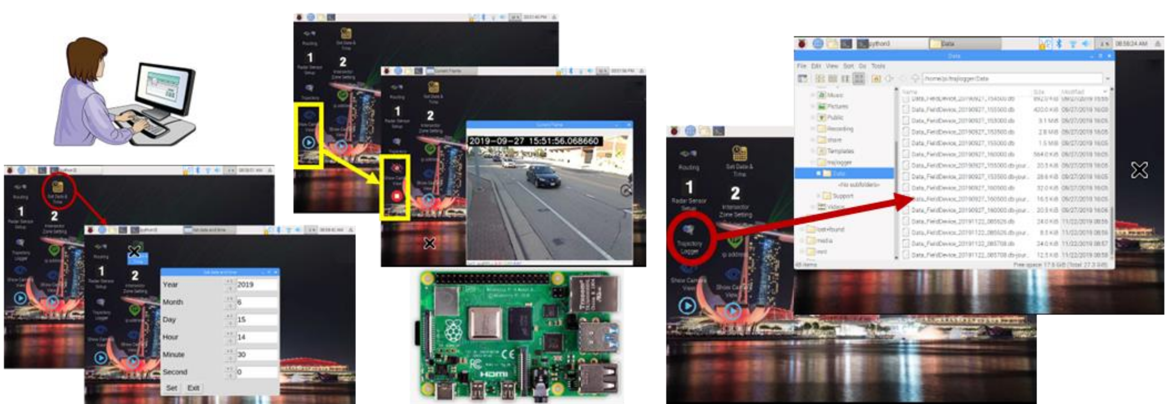
dissertation. I got to use several engineering skills. I never expected to use my electrical knowledge from my undergraduate studies, but I did! I also used the coding skills that I acquired as part of my computer science master's degree. I would like to thank the Makerspace for providing equipment, materials, and tools that helped me assemble my data collection tool.



Assembling board in the Makerspace



Wiring and adding camera



User interface using a Raspberry Pi

Overall system

10.11 Research impact and future goals

In my research, I proposed the use of the time to complete a right turn as a function of the position of the pedestrian within the crosswalk to describe the level of "respect" that drivers have for pedestrians as a new safety measure. We can create similar plots/models to the ones I created for other locations and compare the "respect" towards pedestrians. For example, prior to installing a right-turn flashing yellow arrow to improve the yield to pedestrian behavior of vehicle drivers, we can establish a model like the one shown through field observations. After installation of the right-turn flashing yellow arrow, we can repeat the same data collection and modeling procedure. We can then conduct a comparison of the two models/plots to explain if the installation of the countermeasure had a positive, neutral, or negative impact on the safety behavior observed. In addition, my models showed what affects the time it takes a driver to complete a right turn. This is important to better understand how human drivers interact with pedestrians. This information is very useful and should be used by designers of autonomous vehicles to create self-driving cars that behave in ways that don't confuse human drivers and pedestrians.

I also showed how we can predict the number of crashes using this safety measure and how we can use such prediction models on locations that do not have crash history. Finally, my dissertation showed how we can use available vehicle-detection infrastructure devices to calculate some safety measures. I also created a new data collection tool that combines radar-based vehicle detection systems and cameras. If we continuously calculate safety measures using the new data collection tool, we can establish a safety monitoring program that continuously monitors intersections for the occurrences of near misses. We can then use my procedures to rank the safety of intersections. This data can help agencies by adding objectivity to processes that are often biased towards intersections that have a crash history but ignore intersections that will likely pose safety problems in the future. We can also use the procedures I described with data collected from a driving simulator (figure below) and not just data collected from the field.